NASA MAKE Challenge 2011 Winner: "Bring It Back" Microgravity Kit

Written By: Prashant Rao

TOOLS:

- Hand tools (1)
  Usual suspects
- Multimeter (1)
- Plastic cutting tools (1)
  Tools needed depend on the procedure used to build the acrylic box
- Soldering/desoldering tools (1)
- Thermometer (1)
- Wire stripper/crimper (1)

PARTS:

- Arduino microcontroller (1)
- Adafruit Motor/Stepper/Servo shield (1)
  You will need additional drivers to handle currents of about 1.5 amps A Relay shield is also an option. See: http://www.emartee.com/product/41980/Arduino-Relay-Shield
- Minco THERMOFOIL HEATER (2)
  Size 0.75in x 0.75in (19mm x 19mm)
- Three-axis Accelerometer (1)
- Acrylic sheet (1)
  12in x 12in piece is sufficient for several trials
- Case Fan 50x50x15 5 Volt 12 cfm (1)
- NiMh Batteries 2500 mAh size AA (6)

Batteries can be purchased from several sources.

- battery holder for 2 AA batteries (1)
  Batteries should be side by side to keep length short
- Battery holder, 4xAA (1)
- Wax (5 Oz)
- Steel Balls 1-2 mm diameter (4)
- Tiny figurines 5-8 mm tall (1)

SUMMARY

"Bring It Back" Microgravity Kit by Prashant Rao & Subra Sankaran

Prashant Rao, Ph.D., Principal Engineer, Barrios/Jacobs/ESCG

Subra Sankaran, Ph.D., Senior Thermal Specialist, MEIT/Jacobs/ESCG

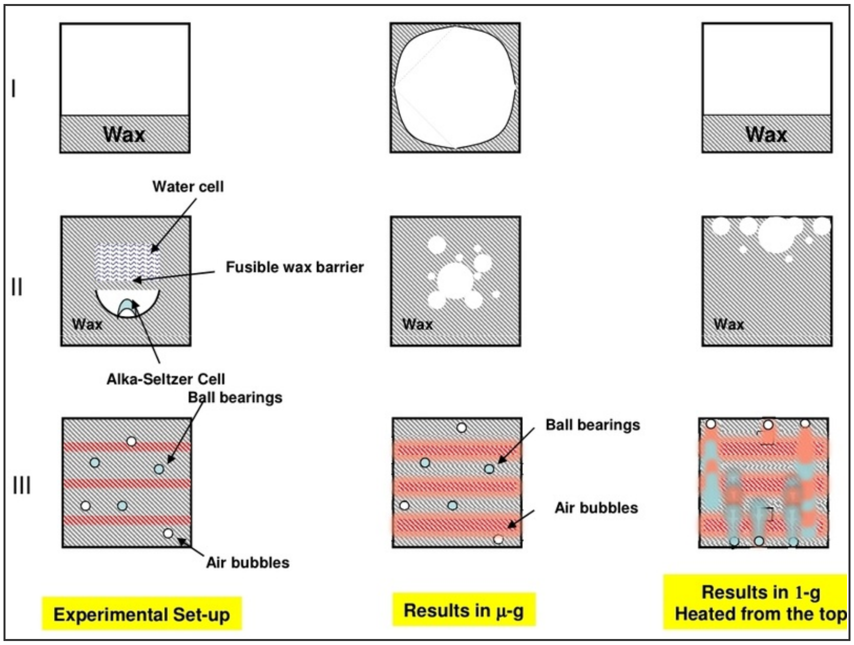
at NASA JSC, 2224 Bay Area Blvd, Houston TX 77058

Three experiments are described here (with suggestions for additional experiments) that use molten wax in different setups to demonstrate important principles of science and engineering. They can be performed using substantially the same equipment, making the kit quite versatile. The experiments demonstrate the dominance of surface tension and wetting effects in the absence of gravity, the lack of buoyancy and its implications, all frozen in wax. Other science concepts related to these experiments are simulated boiling, two-phase fluid flow behavior in micro-gravity, fluid flow and bubble movements induced by temperature gradients, diffusion, melting and freezing in the absence of buoyancy and natural convection, wake flow, and so on.

For these experiment you will need a small airtight container four to five milliliters in volume. Ideally it should not have a very thick wall because we are going to heat the contents with an external heater and we want to heat it up fast but the walls should be thick enough to withstand the increase in pressure due to heating and due to the expansion of the wax when it melts (about 10%). You will need to experiment with different containers or make one with acrylic sheet. We like a container with internal dimensions of 2 cm x 2 cm x 1 cm. This is

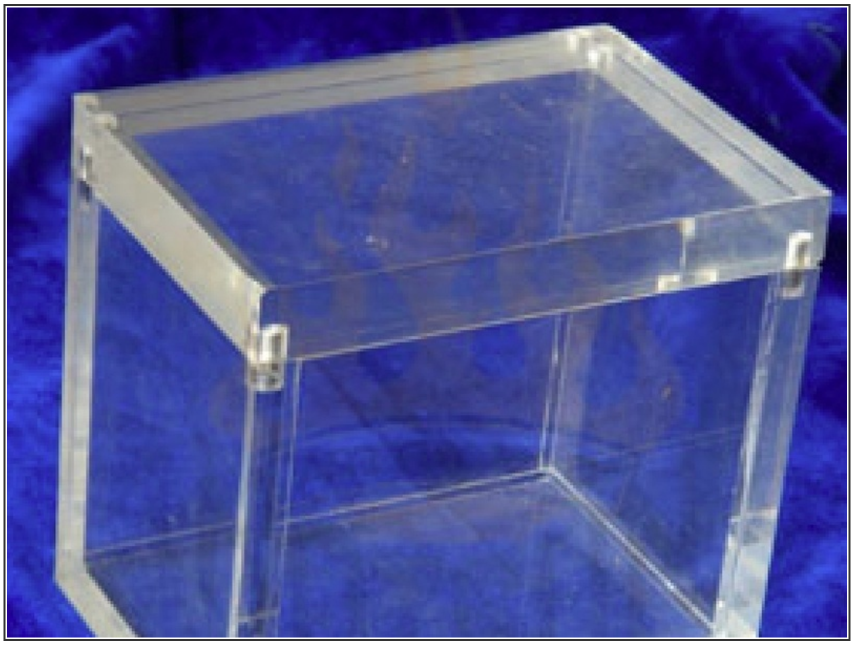
pretty small but we need to heat and cool the contents fairly rapidly. Instructions for making boxes using acrylic sheets are available on the internet. The acrylic sheets used for a box of this size should be about 0.08" (1/8 in) thick. The pressure load when the box is heated will be as much as a 1.1 kg (2.4 lb) weight on the 2 cm x 2 cm face.

Step 1 — NASA MAKE Challenge 2011 Winner: "Bring It Back" Microgravity Kit



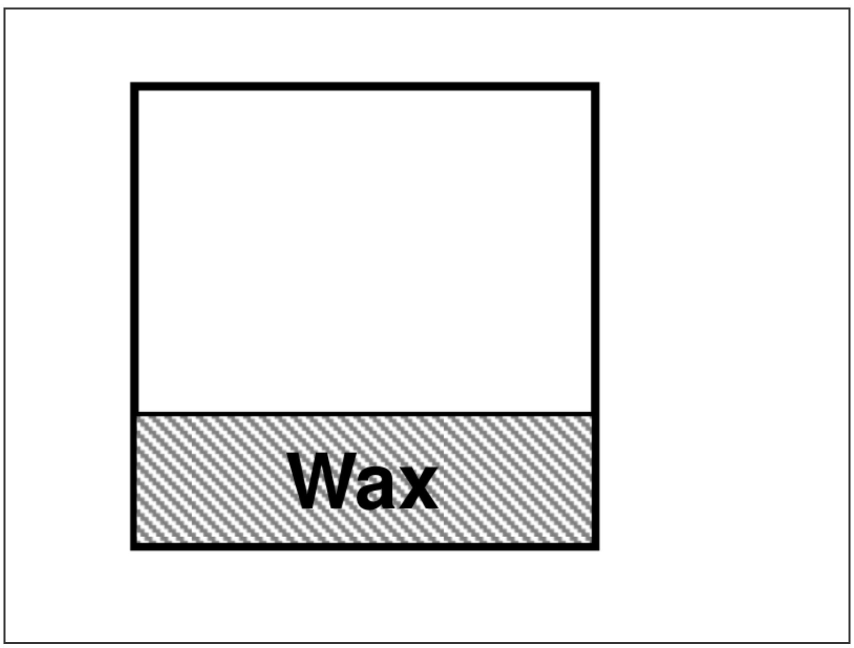
- You will be creating three different experimental setups for use within a single 10x10x10cm CubeSat module.
  - In terms of technological applications, the first is equivalent to studying the fuel location in a liquid propellant tank during space travel. The second is equivalent to studying boiling heat transfer (e.g., see picture from Merte's experiments in the ISS) in space, and the third brings in multiple effects of absence of gravity.
  - Some of the actual space flight experiments that are closely related these wax experiments are: zero boil off test, Liquid Acquisition Devices in fuel tanks, several boiling heat transfer experiments, thermocapillary migration of bubbles, studies of liquid bridges / electro hydro dynamics, corner flows, and isothermal dentritic growth experiment shown in the picture below.

Step 2



- Prepare the 2 cm x 2 cm box with one 2 cm x 2 cm face open. Instructions for making acrylic boxes are available on the internet with Youtube being a particularly rich source of tutorials.

Step 3

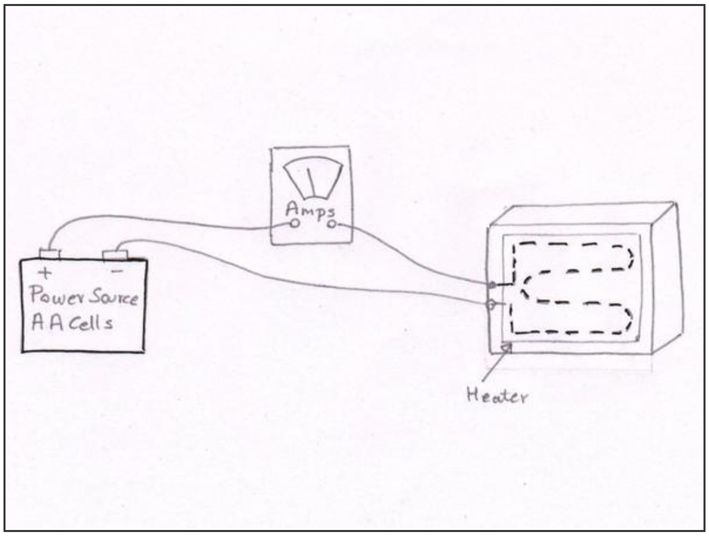


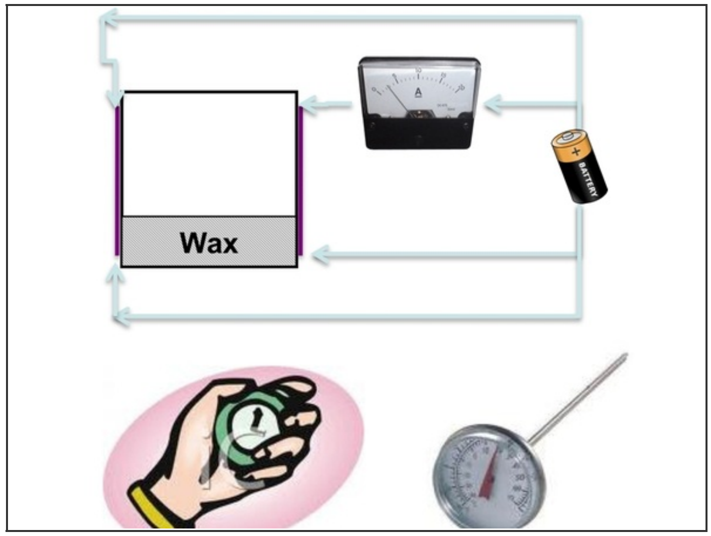
- Pour about 1 gram of molten wax into the container. It will be more helpful to use colored wax because it will be easier to see.
- Seal the box immediately after pouring the wax when it is still hot. This may help create a negative pressure inside the box when it cools and help reduce the pressure load on the box when it is heated.
- Note: The wax expands up to 10% in volume when it melts! The pressure rise in the box can be calculated to see if the box can withstand the increase in pressure.

Step 4

- Mount the heaters on the two large faces using stretch tape or shrink band.
- Depending on the microgravity time available, it is desirable to use a thinner box. Also, place the heaters on the opposite sides of the box to achieve uniform heating.

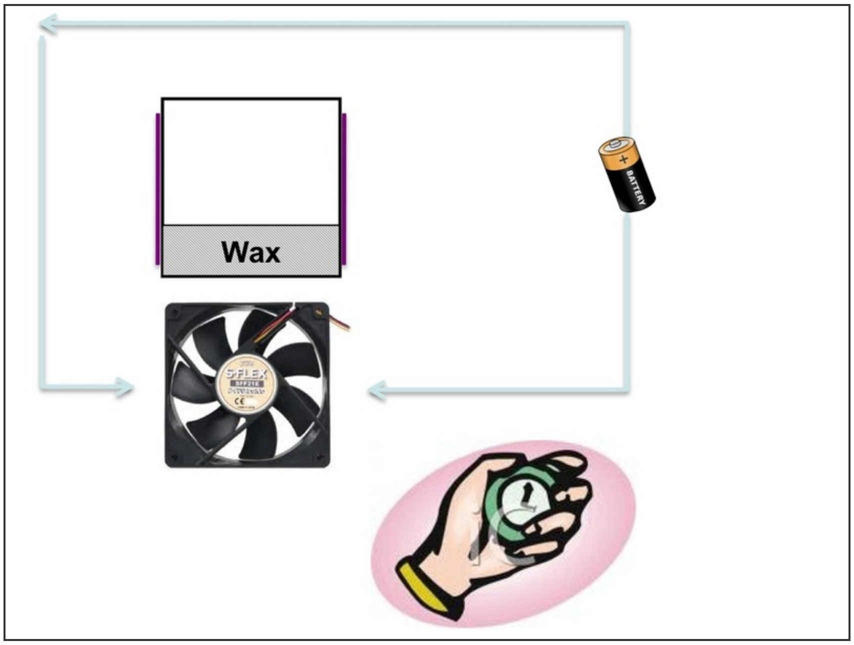
Step 5





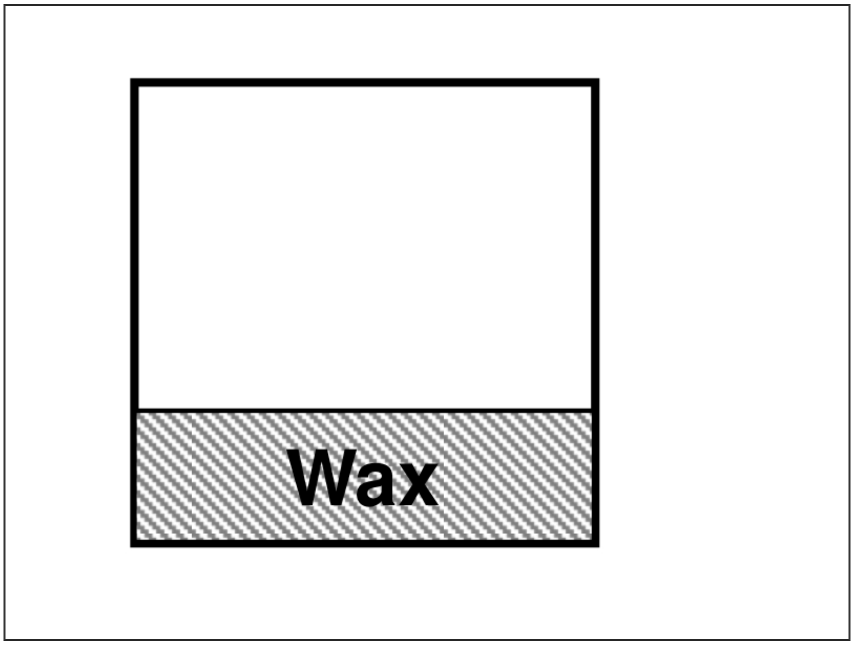
- Connect the heaters in parallel to a 6 volt DC power supply and run it until all the wax is melted. It might be easier to see if the wax is melted if you place the box on one of the smaller sides and watch the wax flow.
- Connect an Ammeter in series with one of the heaters to note the current draw. This will be helpful later in choosing a power source.
- Note the ambient temperature.
- Switch off the heaters once the wax is melted. Note the time taken to melt the wax.
- Calculate the energy needed to heat the box and the wax to the desired state, and predict the time needed for the heaters to be powered on. You will need material properties like the specific heat of the wax and box material, latent heat of the wax and power output of the heaters. The actual time taken will be longer than this rough calculation because the efficiency of the system will be less than 100%. Study the effect of natural convection and radiation in this 1g calculation.

Step 6



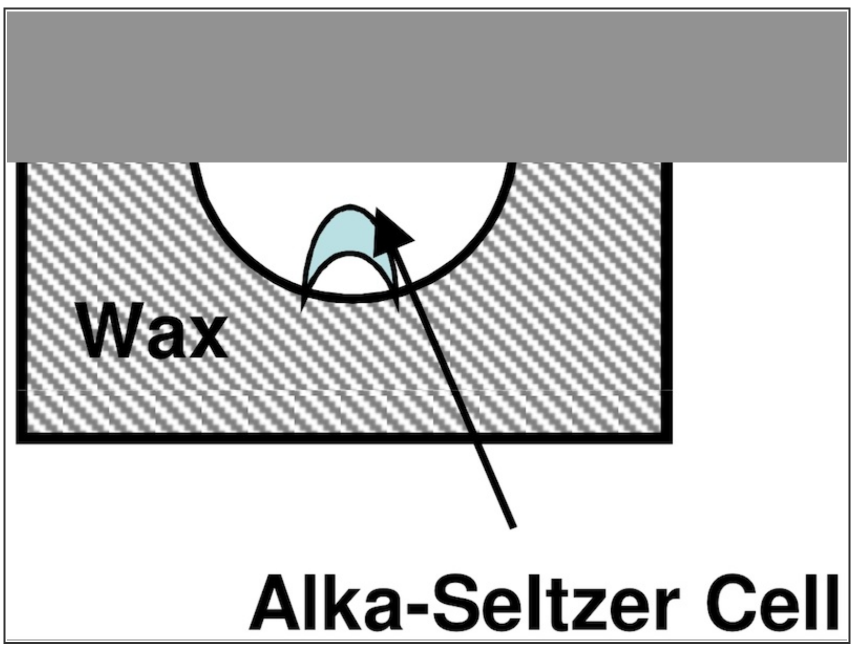
- Wait for the wax to solidify. You can tilt the box slightly to see if it flows or if there is distortion in the crust that forms on top. If there is distortion in the crust it indicates that it is thin and the wax could break and flow through if tilted far enough.
- Note the time taken for the wax to solidify. What we really want to know is – how long does it take for a thick crust to form that will hold the shape of the wax? The answer to this question will fall in a range which is sufficient for our purposes. (Remember that the heat transfer is going to be less efficient than this in microgravity without convective heat transfer inside and outside the box.)
- Now you are ready to design the experimental setup for Experiment 1 to go to space. Next we will work on Experiment 2.

Step 7



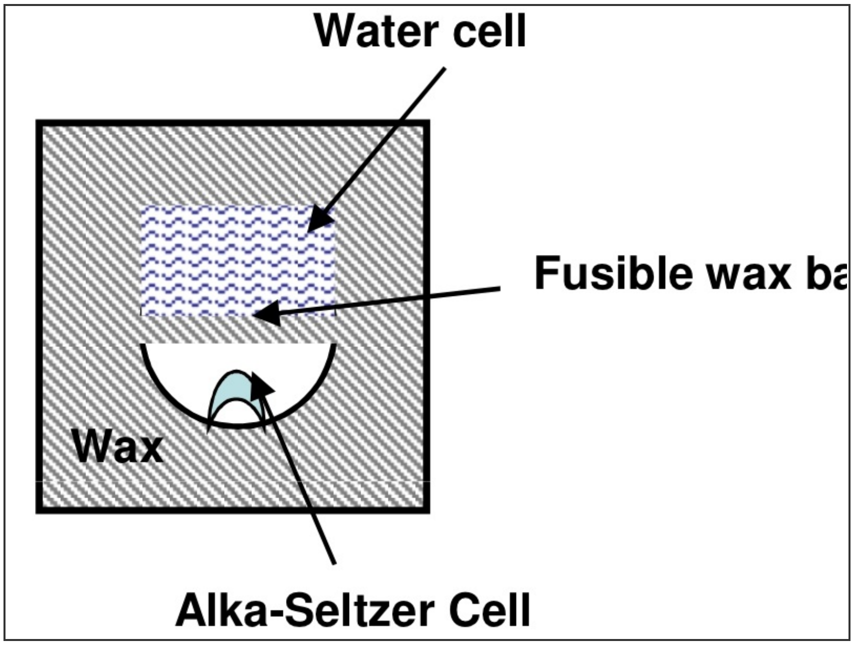
- Prepare the box as for Experiment 1.
- You will need about 2.5 grams of clear wax for this experiment.
- Pour in about 1 gram of molten wax into the box and wait for it to cool.

Step 8



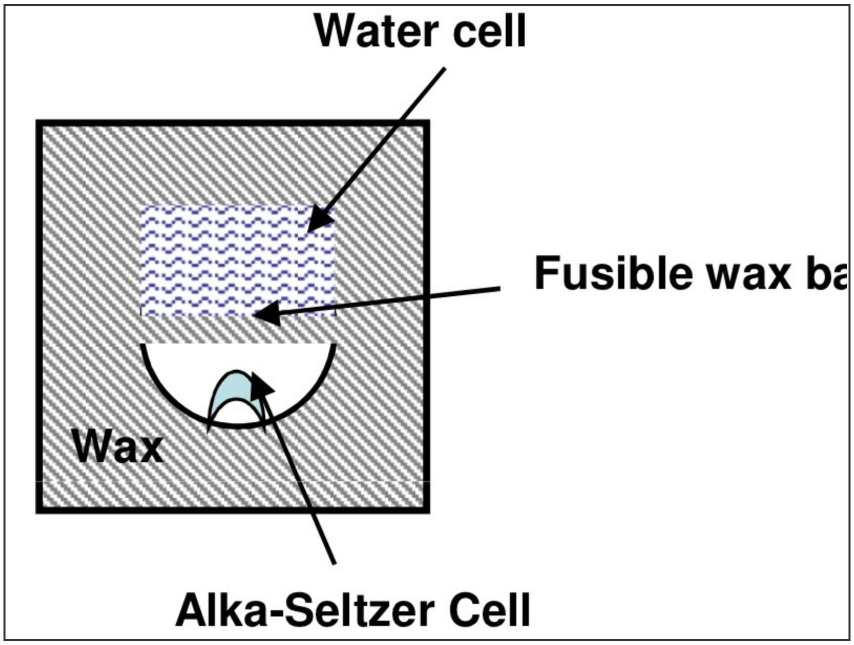
- Pour in about 1 gram of molten wax into the box and wait for it to cool.
- Now you will embed a pocket of Alka-Seltzer in the wax. Here is one way to do it. When the wax is still soft, scoop out a hemispherical depression in the center 4-5 mm in diameter.
- Put in a small amount of coarsely powered Alka-Seltzer into the depression.

Step 9



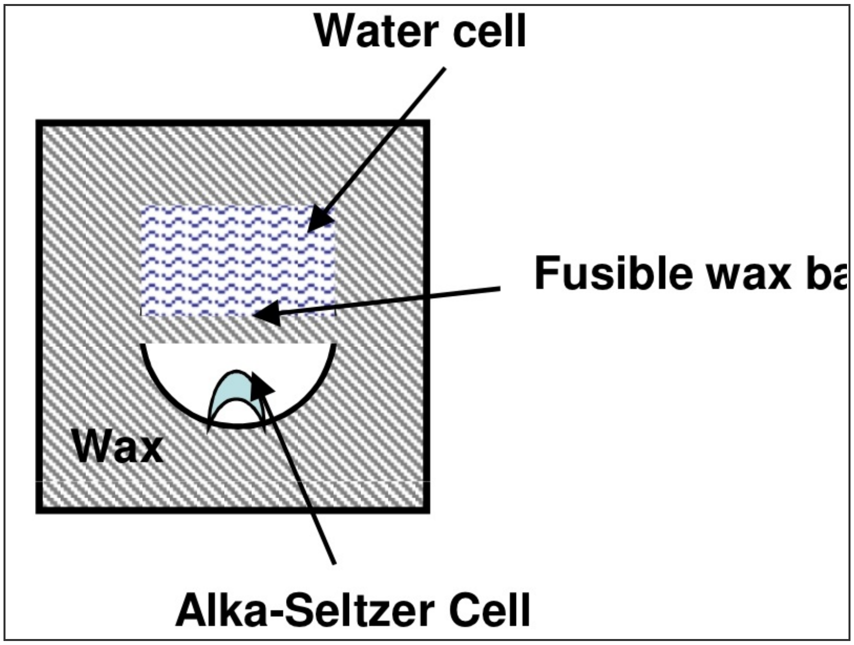
- Pour a few drops of colored molten wax on a warmed metal surface. A shallow saucepan will do nicely. The pan should be warm enough to keep the wax soft but not warm enough to melt it.
- The drops will form a film on the saucepan surface. Its diameter should be about 1.5 times the diameter of the Alka-Seltzer cell. Peel or scrape it off once it is solid enough.
- Cover the Alka-Seltzer cell with the film. Press it in place and rub it lightly with the back of a heated spoon for a second or two so that it fuses well into the wax base but does not melt and mix with the Alka-Seltzer. This calls for trial and error to adjust the pressure from the spoon and time. You have just put the fusible wax barrier in place.
- Be careful with the spoon. You don’t want to melt the fusible wax barrier.

Step 10



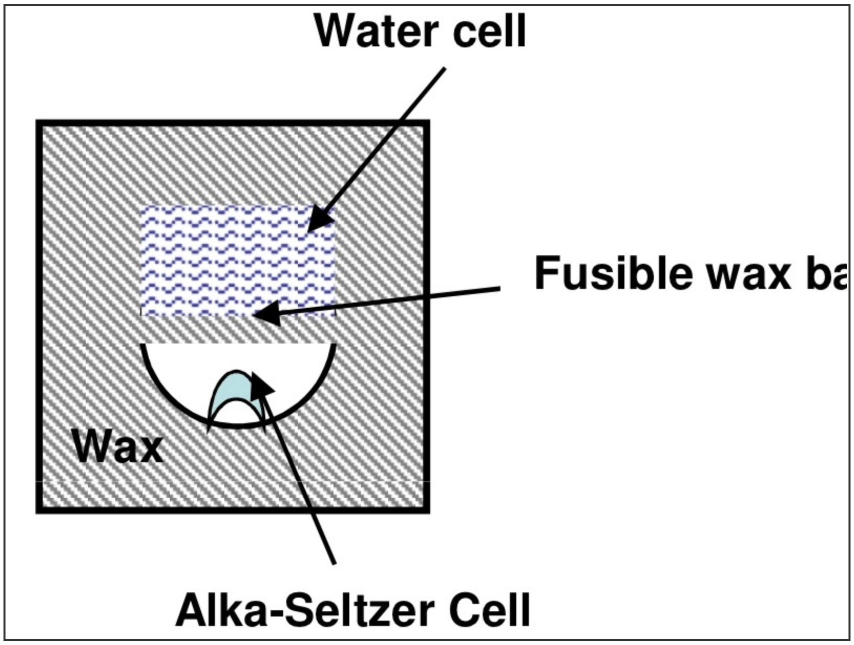
- Pour about 1 gram of the molten wax into the box. (Or, place a sheet/block of wax over and gently melt and fuse with the previous layer).The temperature of the wax should be just at or slightly above the melting point so that is almost about to solidify. This is because you definitely do not want to melt the fusible wax barrier.
- Repeat – You do not want to melt the fusible wax barrier!

Step 11



- When the wax is still soft but solid, scoop out a depression right on top of the Alka-Seltzer cell about the same diameter and deep enough to reach the fusible wax barrier. This is where you will realize the utility of a colored barrier. You can tell when you've reached it! This is the water cell.
- Fill the water cell with water so that the top of the meniscus is level with the top surface of the wax. It might be more interesting if you color the water with a couple of drops of food coloring.
- Cover the water cell with a clear wax film in a manner similar to the fusible wax barrier.

Step 12

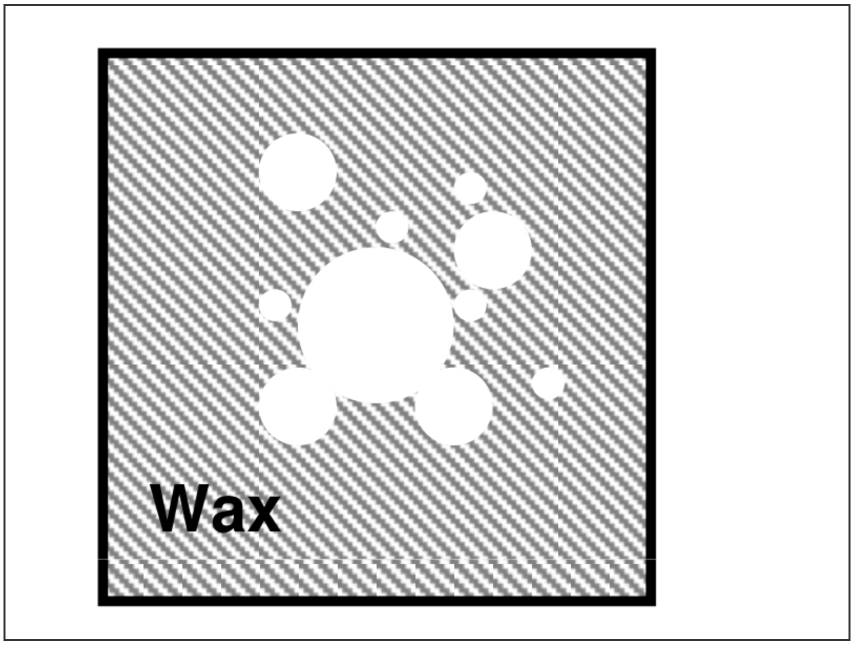


- Cover the water cell with a clear wax film in a manner similar to the fusible wax barrier.
- Melt the remaining wax and pour it into the box. Again, the temperature of this wax should be at about the melting point so that it doesn't melt the water barrier. At this point the container should be about 2/3 to 3/4 full, not more. You want to leave space for the wax to expand.
- Seal the box immediately after pouring the last layer when the wax is still hot. This may help create a negative pressure inside the box when it cools and help reduce the pressure load on the box when it is heated.

Step 13

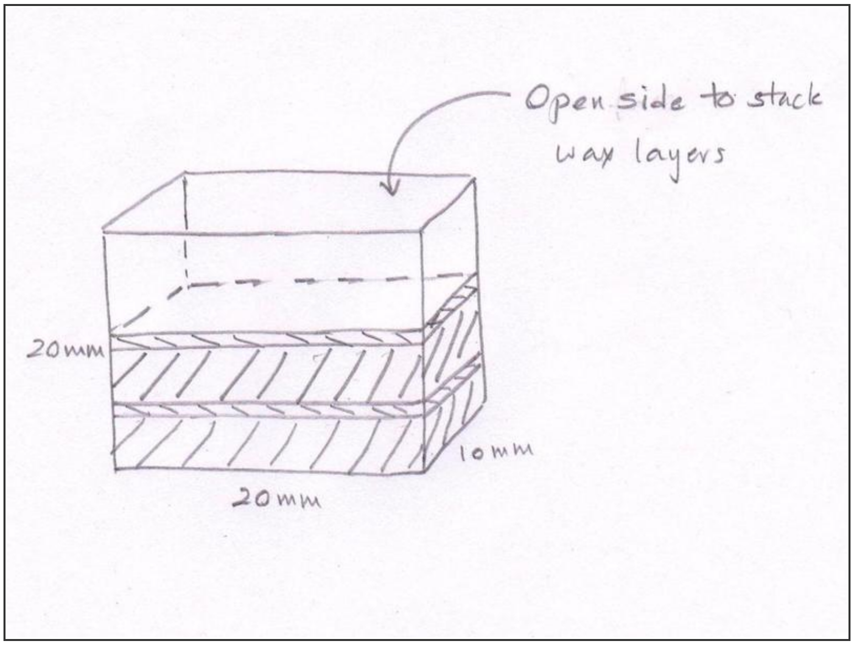
- Mount the heaters on the box to the two large faces of the box using stretch tape or shrink band.

Step 14 — For the Ground Test:



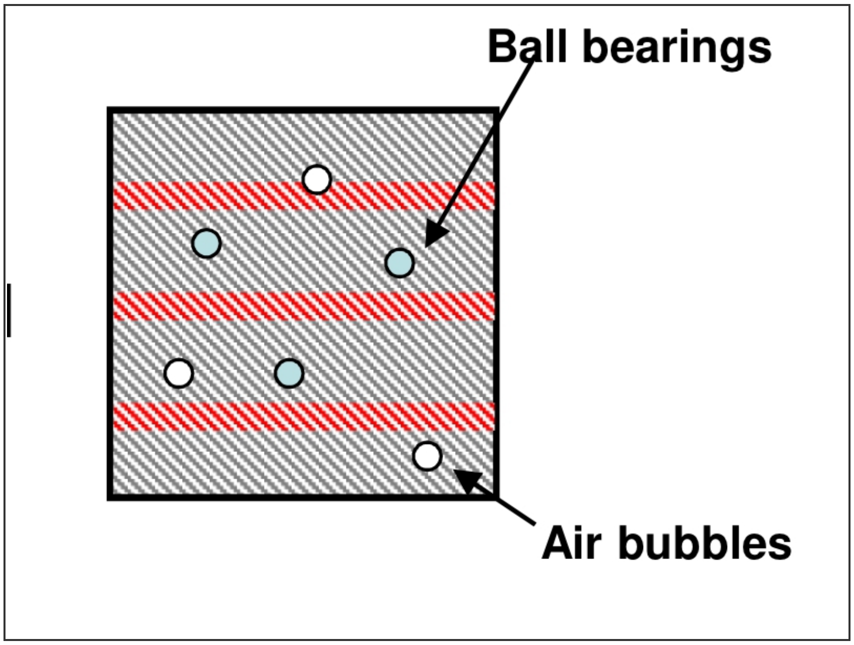
- Note the ambient temperature.
- Attach the heaters in parallel to a 6-volt supply with a Ammeter in series with at least one of the heaters.
- Place the box with side with the Alka-Seltzer face down.
- Run the heaters until the wax is melted. When the wax is melted, the fusible wax barrier should also melt, and since the molten wax cannot remain as a sheet, will allow the water and Alka-Seltzer to come into contact and react.
- Note the time and switch off the heaters. Note the time taken for the wax to solidify. (Remember that the heat transfer is going to be less efficient and very different from this in 0-g without convective heat transfer inside and outside the box.)
- Now you are ready to design the experimental setup for Experiment 2 to go to space. Next we will work on Experiment 3.

Step 15



- From here on is described the setup for Experiment 3
- Prepare the acrylic box so that the only open face is one of the small sides. This is because you are going to stack the wax in layers.

Step 16



- You will need wax of two or three colors for this experiment with a total weight of about 2.5 grams.
- Pour the molten wax into the box in layers waiting for the previous layer to solidify each time. (Or, you can do this experiment by merely placing several layers of differently colored wax on top of each other, along with embedding other objects and bubbles appropriately.) Thinner layers are better than thick ones to better visualize the patterns that you should see after the experiment. However it will take longer to prepare the experiment.
- As you prepare the layers, embed small items of various densities in the wax. You can try small ball bearings, bubbles (use the method given for Experiment 2), tiny figurines, etc.
- The box should be about 2/3 to 3/4 full when you are done.
- Seal the box immediately after pouring the last layer when the wax is still hot. This may help create a negative pressure inside the box when it cools and help reduce the pressure load on the box when it is heated.

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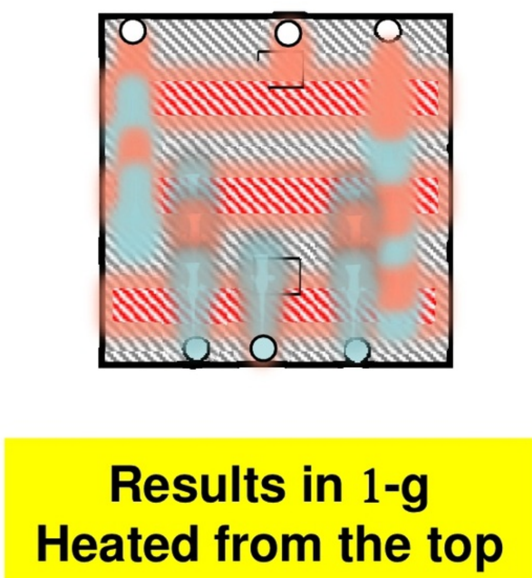
Step 17

- Mount the heaters and orient the box, say, on one of the small sides so that the wax layers are horizontal. You could also experiment with a vertical orientation.

Step 18



- Run a ground test. Note the experimental parameters as for Experiments 1 and 2.
- Remember that the heat transfer is going to be less efficient and the flow patterns will be very different from this in microgravity without buoyancy and convective heat transfer inside and outside the box.

Step 19 — Preparing the Experiments for Microgravity

- You will need to use the Arduino or some other similar microcontroller for the experiment. A microcontroller is required to determine the correct time to switch on and switch off the heaters and to run the fan. It is also needed to run a camera and control the lighting if you should choose to add those optional items.
- You will also need the capability of switching currents of up to 1.5 Amps for each of the heaters and up to about 0.5 Amps for the cooling fan. The Arduino does not have the native capacity to control such large currents so you will need a power or motor shield or a relay shield in addition.
- For the power supply we suggest six NiMh batteries in AA size of good quality and high energy capacity connected in series. NiCad batteries could also be an option. Both NiMh and NiCad batteries can withstand a high current draw but the NiCad battery usually has a lower total capacity (usually measured in mAh or milli-Ampere hour).
- Instructions for developing the circuitry for your experiment should be obtained elsewhere. There is a wealth of information available on the internet for using the Arduino microcontroller.

Step 20 — Using the Flight Plan

Flight Plan / Experiment TimeLine

No.	Item	Action	Notes
1	Accelerometer	ON	All the time
2	Heaters	ON	As soon as accelerometer senses ug after the high g ascent
3	Heaters	OFF	In x seconds,
4	Fan	On	In x+1 second
5	Fan	Off	In y seconds

- The flight plan is crucial to the experiment. The time spent in microgravity is very limited and the available time has to be budgeted very carefully.
- A three-axis accelerometer like the ADXL335 needs to be used to measure the magnitude of the total acceleration in all three directions.
- You will need to use your ground-based measurements to decide when the heaters should be turned on and off and when the fan should be run and for how long.

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